

# ***OPTICAL INTERFEROMETER TESTBED***

Gary H. Blackwood

MIT Space Engineering Research Center  
3rd Annual Symposium

July 1 1991

160303  
N93-28168

# ***OPTICAL INTERFEROMETER TESTBED:***

## ***OUTLINE***

1. Motivation for a laboratory testbed of a space based interferometer
2. Description of testbed in context of Controlled Structures Technology
  - performance metric
  - control hardware
3. Overview of testbed research in context of Controlled Structures Technology
  - structural design
  - disturbances and performance
  - sensor/actuator design
  - local/low authority control
  - global/high authority control

# ***OPTICAL INTERFEROMETER TESTBED PROGRAM***

Objective: to provide a versatile environment for well controlled experiments on complete controlled structure systems

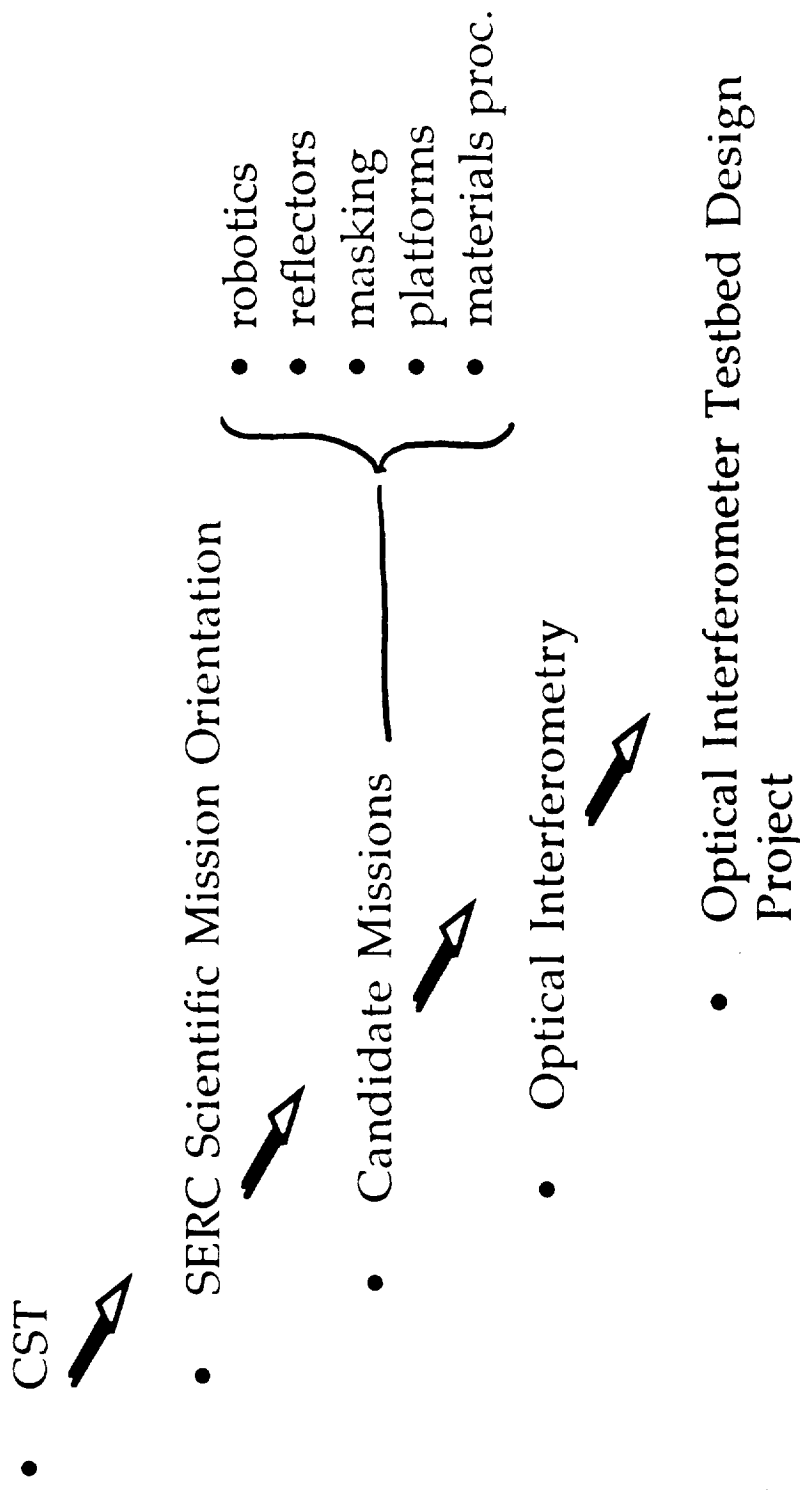
Testbed is designed to capture the essential configuration, physics, and performance metric of actual spacecraft

Testbed was designed and constructed by students, staff, and faculty as a facility class experiment

Students will conduct their thesis experiment on the testbed by changing out structural components, control hardware and software

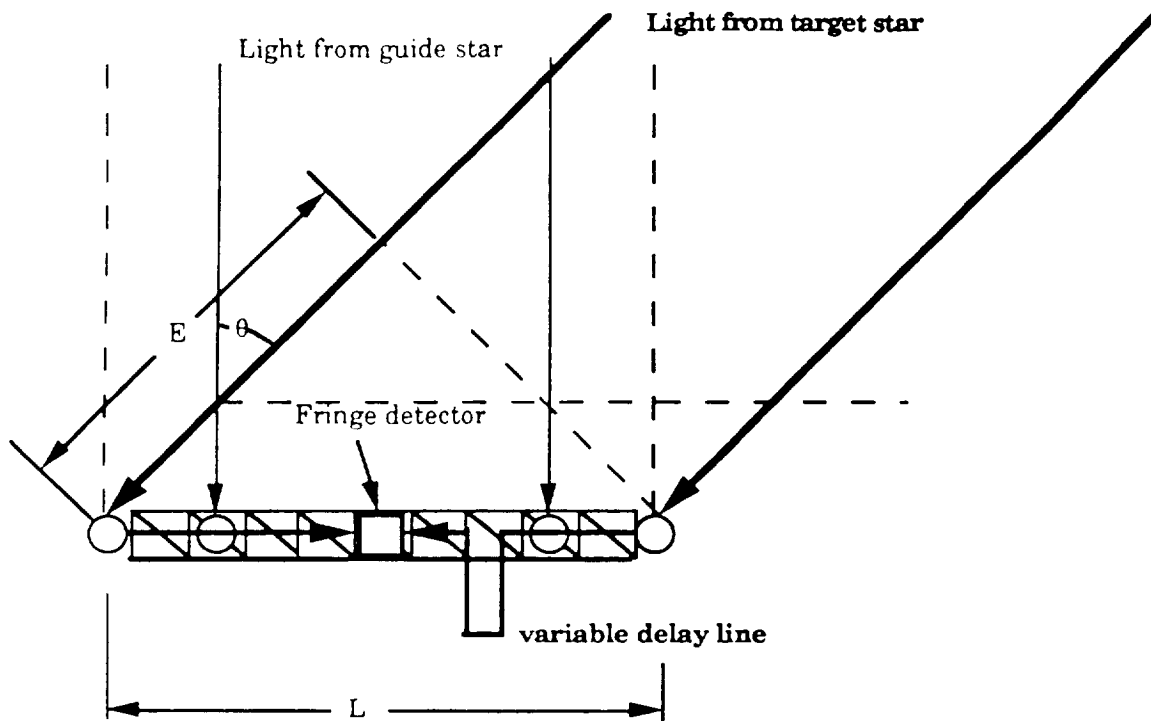
Process provides a realistic evaluation/demonstration of new approaches in *controlled structure design*

# A Testbed Based on a Space-Based Optical Interferometer



## A Space-Based Interferometer

- used for astrometry:
  - measure baseline and delay lines using metrology system
- used for imaging
  - measure intensity (mag) and phase (via delay line distance) of central fringe of interference pattern
  - vary baseline and rotate siderostats about LOS to target star by rigid body motion
  - reconstruct image from 2-D spatial IFT of the measured intensity



# ***OPTICAL METROLOGY***

Unique feature of testbed is multi-axis laser metrology

At 3 mock siderostat locations are precision 3 axis active mirror mounts holding common endpoint retroreflectors (cat's eyes)

Fourth vertex holds laser and other optics

Use commercially available 670  $\mu$ Watt laser from Hewlett-Packard

VME based fringe counting provides seamless link to real time controller

Optical components provide 5 laser pathlength measurements:

- defines baseline for metrology
- define “total starlight differential pathlength error” metric, simulating both internal and external error sources
- a subset of these measurements are available for feedback



# ***SENSORS AND ACTUATORS***

## **Sensors for Identification and Control**

- 32 Kistler accelerometers for modal identifications testing
- 9 Sunstrand micro-g accelerometers mounted at performance-critical locations
- 5 channels of laser measurement
- strain gages and load cells collocated with active struts

## **Actuators for Identification and Control**

- 3 active struts capable of 60 microns of stroke and 250 Newtons of force at high bandwidth (Physik Instrumente)
- 3 three-axis precision mirror actuators (custom) at each mock siderostat location
- Passively shunted piezoelectric struts



## *Real Time Control Hardware*

- VME based digital control hardware
  - 68030 processor
  - CSPI vector processor
- Capability:
  - 16 inputs
  - 10 outputs
  - 32 states at 1000 Hz; scales by  $(n_s + n_i) * (n_s + n_o)$
- Direct link to six HP laser measurement boards
- Control design in MATLAB on Sun SparcStation
- Analog: circuits for displacement and velocity feedback to active struts

# A CST DESIGN METHODOLOGY

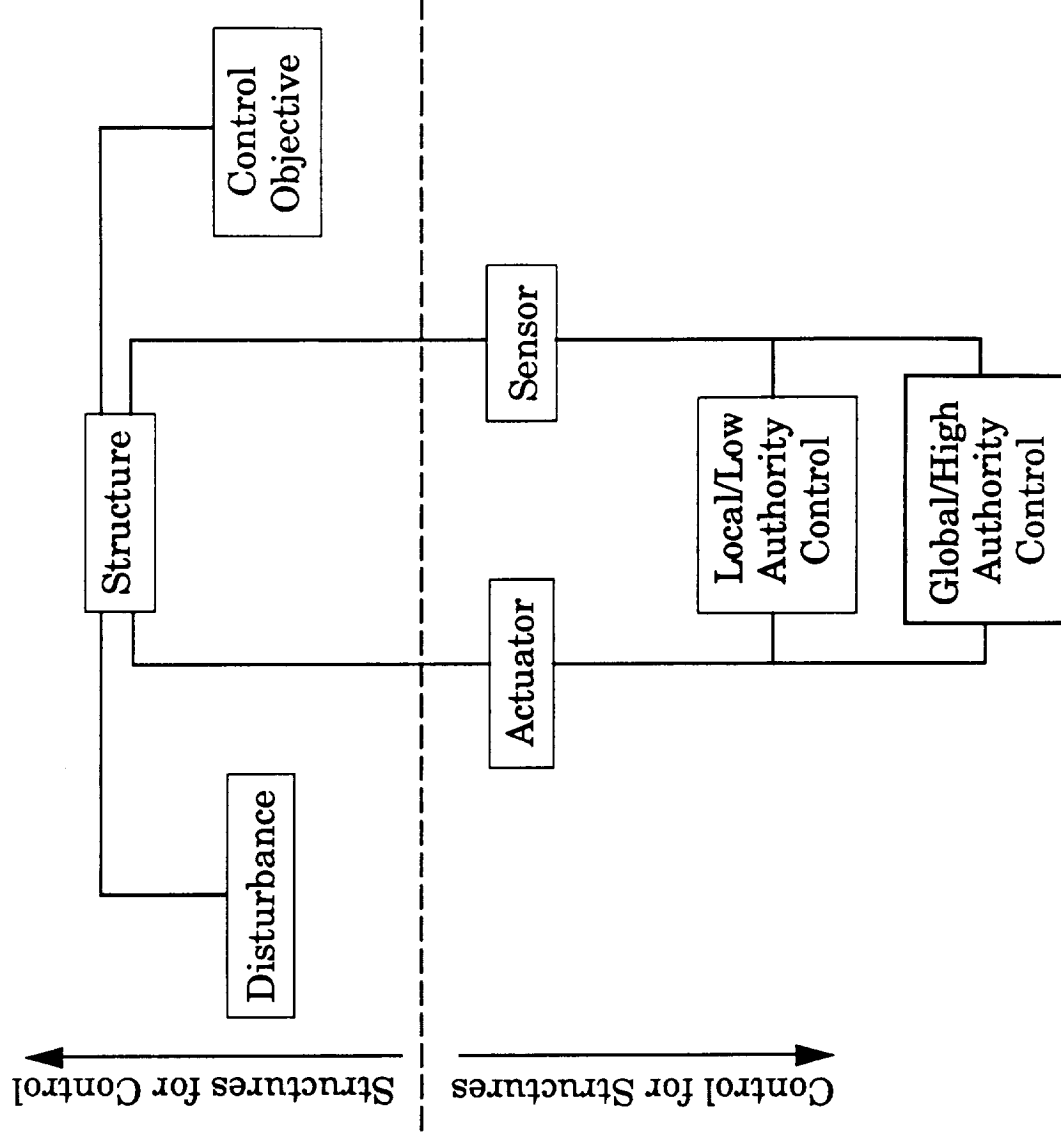
1. Design structure.

2. Design disturbances and control objective.

3. Design actuator and sensor.

4. Design local/low authority control.

5. Design high authority control.



# ***INTERFEROMETER: EXAMPLE OF CST DESIGN***

The interferometer will be used not only as a testbed for the elements of Controlled Structures Technology but also for the evolution of the design process.

## **Step 0 - Mission Requirement Specification**

Disturbance selected from spacecraft experience.  
Performance metric established which captures challenge of real spacecraft mission.

## **Step 1 - Design Structure**

Structure chosen for “rigid” alignment of primary performance measures - optical elements of the interferometer  
Structure serves as “host” to robust control  
Passive damping augmentation for performance and robustness

## **Step 2 - Design disturbances and control objective**

Mount onboard disturbances at locations of lower disturbabality  
Passive and active isolation at source and output

# ***INTERFEROMETER: EXAMPLE OF CST DESIGN***

## **Step 3 - Design Actuator and Sensor**

- pole-zero analysis
- actuator and sensor combinations for active isolation
- induced strain actuators
- actuator and sensor placement for global control
- quasi-static shape control

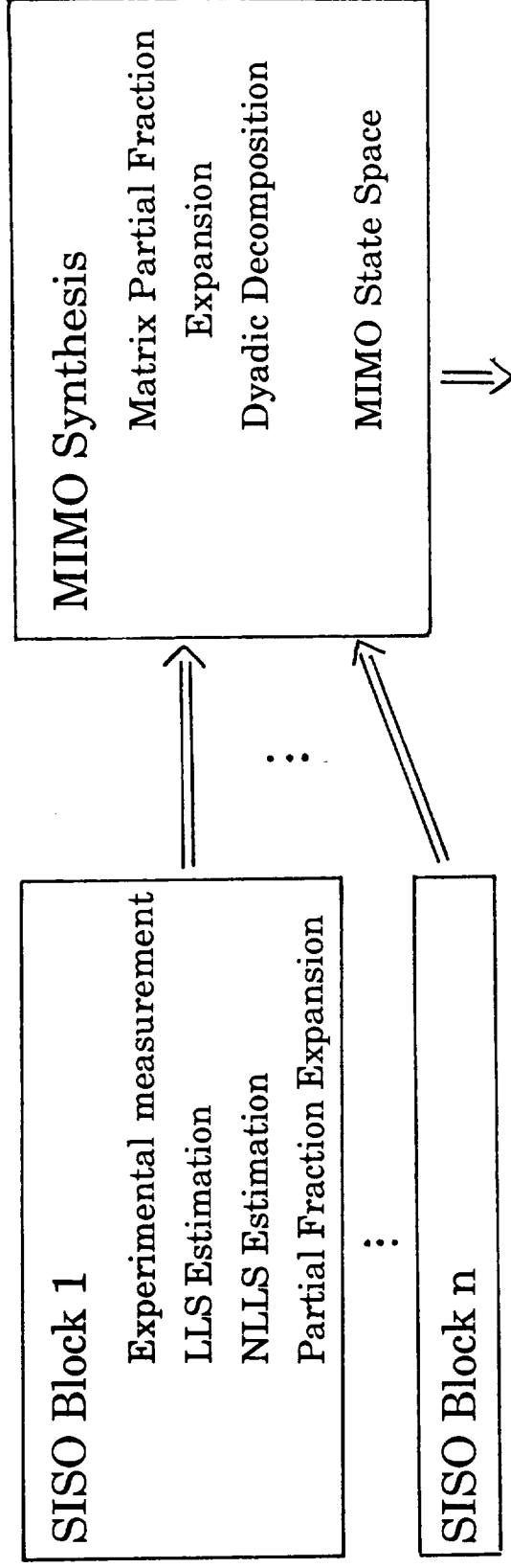
## **Step 4 - Local/Low Authority Control**

- impedance matching
- wave control
- active isolation at disturbance input and at quiet payloads

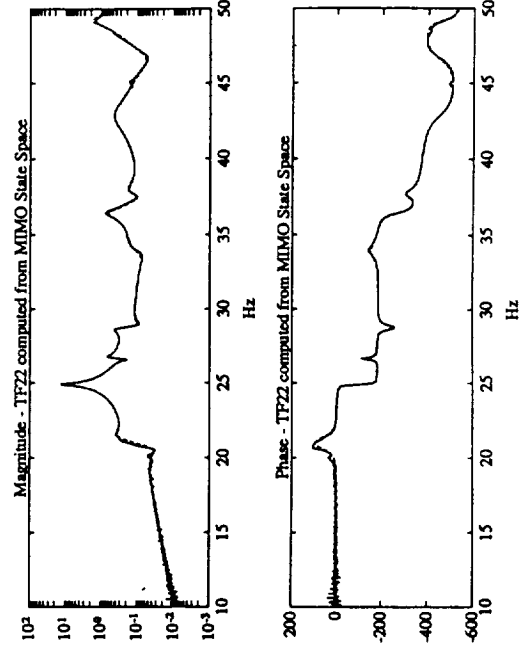
## **Step 5 - Global/High Authority Control**

- modelling and MIMO identification for control
- global control using distributed active struts
- heirarchic control formulation to simultaneously optimize
  - local and global controllers

# IDENTIFICATION FOR MIMO CONTROL



Strut 3 to Accel. 8



Model Validation

— experiment  
----- model

# FEM/ID CORRELATION FOR THE NAKED TRUSS

Frequencies		Modeshapes	
Measured	FEM 1	FEM 2	
31.35 Hz	suspension		Overall agreement with FEM modeshapes
31.75 Hz	suspension		
(35.1) Hz	3.5 %	0.4 %	<u>Current Issues</u>  Assessment of accuracy of measured residues for structure with high modal density  Correlation for incomplete ID and degenerated modes  Correction , based on ID results, of global parameters, to match the frequencies  Correction, based on ID results, of local parameters, to match the modeshapes
35.1 Hz	3.5 %	0.4 %	
38.9 Hz	4.7 %	1.8 %	
(38.9) Hz	4.7 %	1.8 %	
39.4 Hz	3.5 %	0.6 %	
43.3 Hz	4.0 %	0.9 %	
43.7 Hz	0.2 %	0.1 %	
(43.7) Hz	3.2 %	0.1 %	
52.1 Hz	3.3 %	0.2 %	
54.7 Hz	3.3 %	0.6 %	
55.2 Hz	2.4 %	-0.3 %	
55.6 Hz	2.4 %	-0.4 %	
62.7 Hz	suspension		
63.4 Hz	suspension		
94.1 Hz	suspension		
94.8 Hz	suspension		
95.0 Hz	suspension		
100.8 Hz	3.9 %	2.6 %	
101.7 Hz	2.9 %	1.8 %	
102.0 Hz	2.6 %	1.6 %	

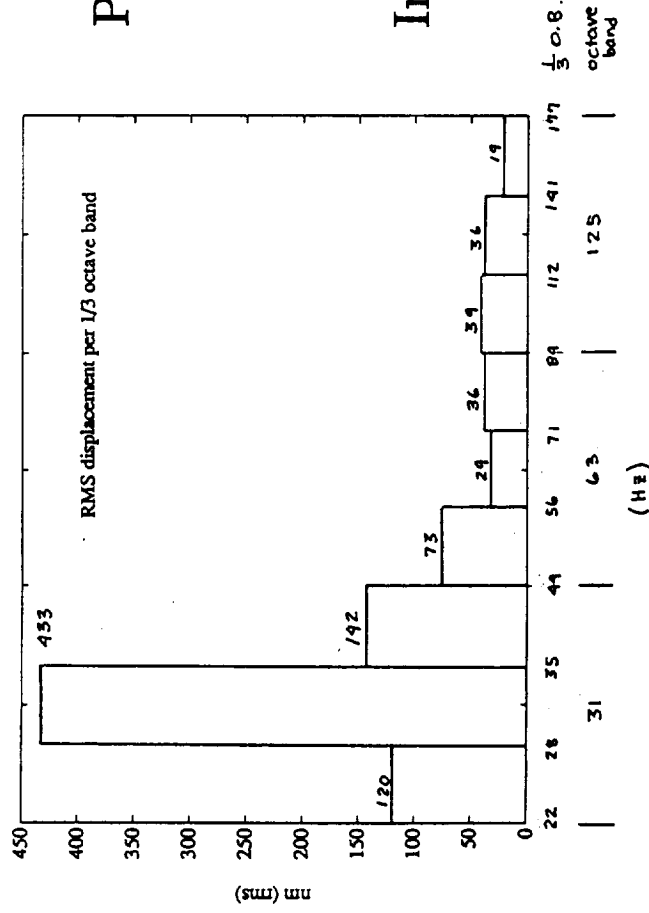
# ***DISTURBANCE MODELLING***

Performance degradation due primarily to disturbances from reaction wheels and other on-board machinery. Disturbance level at output expected to be 500 nm (rms) on full scale

Performance metric is not a function of baseline. Scale lab disturbance to same level of 500 nm (rms)

Disturbance source is piezo actuator mounted to vertex; two disturbances modelled are:

- broadband disturbance
- slowly time varying narrowband disturbance



Pathlength error due to broadband disturbance modeled using Statistical Energy Analysis, assuming a typical disturbance input location.

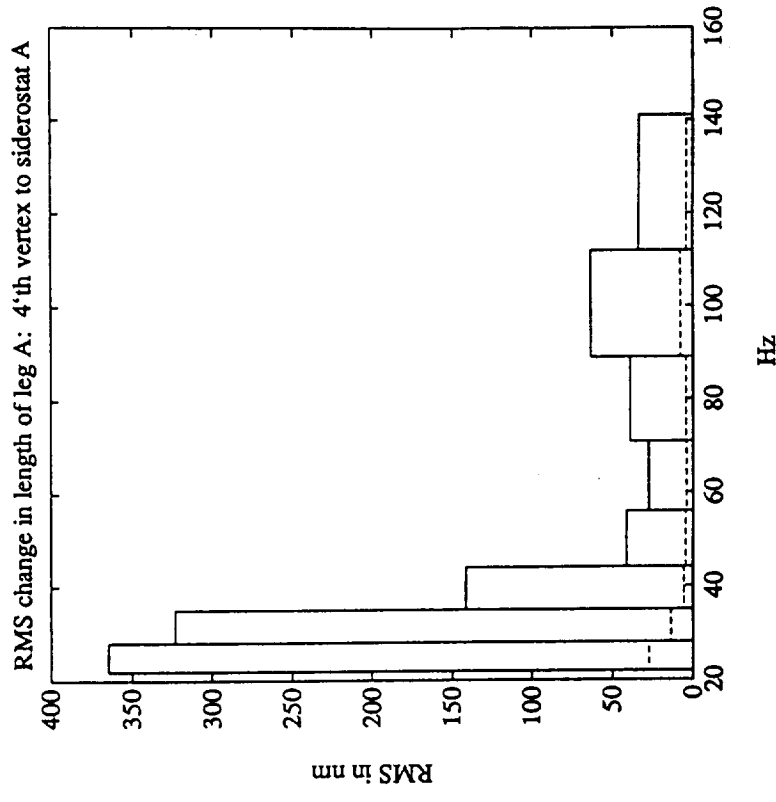
Indicates that 99% of the performance degradation occurs between 20 and 60 Hz.

# ***DISTURBANCE SOURCE IMPLEMENTATION***

Goal: Use 3-axis piezoelectric disturbance source to implement the broadband disturbance spectrum resulting in 500 nm (rms) pathlength error

Test: Measured optical pathlength from the fourth vertex to siderostat A with the disturbance source on and off. Computed the RMS change in length over 1/3 Octave bands.

Results: Disturbance source does degrade the pathlength as expected while concentrating energy in vicinity of first few structural modes.



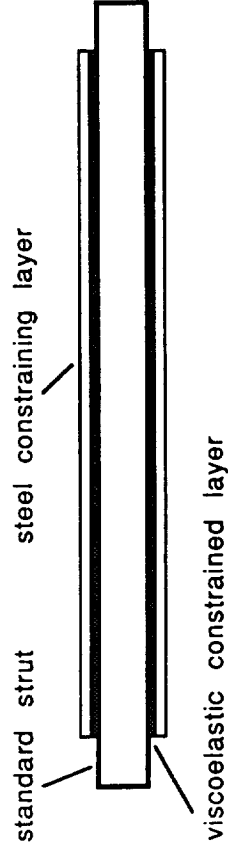


# STRUCTURE DESIGN: PASSIVE DAMPING

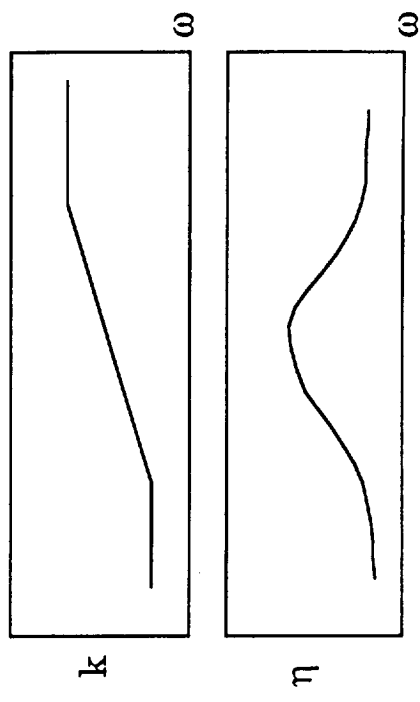
- damping provides some performance within bandwidth
- adds robustness to plant in rolloff region
- improves performance of high authority controllers within bandwidth, which are sensitive to frequency modelling errors

## Option: Constrained Layer Viscoelastic struts

- advantages: inexpensive, easy to make
- disadvantages: temperature sensitive, loss factor not high (.05)  
many struts are required



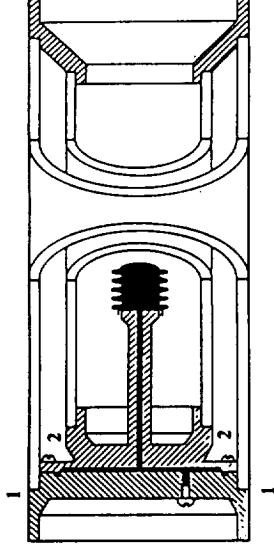
Typical damped strut frequency response



# STRUCTURE DESIGN: PASSIVE DAMPING

## Option: Honeywell D-Strut Passive Damper

- can be tailored for specific structural impedances
- struts have high loss factor (1.5); fewer struts will be necessary
- analytical study: D-Struts placed in locations of highest weighted strain energy; spectrum of disturbance at pathlength output is improved.



a) Inner-Outer Tube Strut

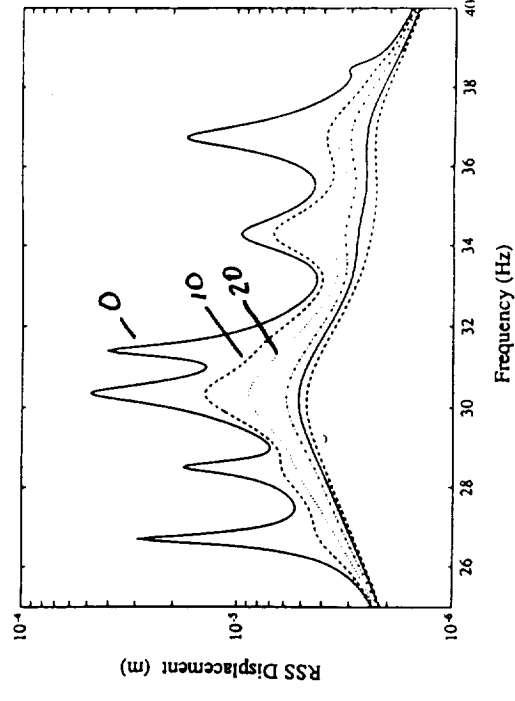
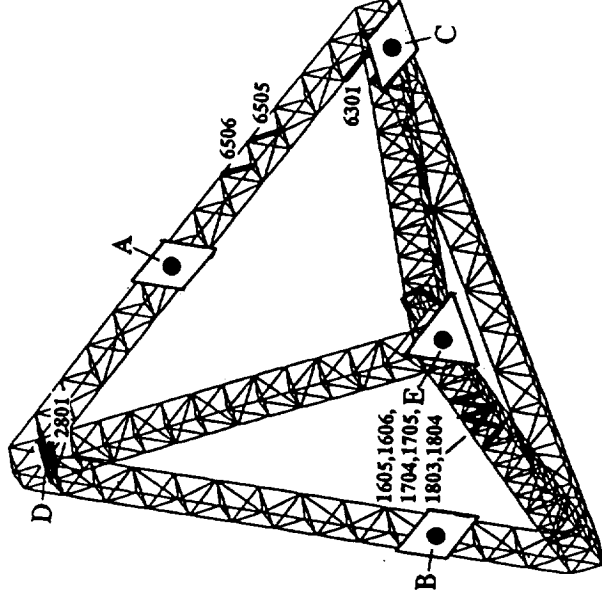
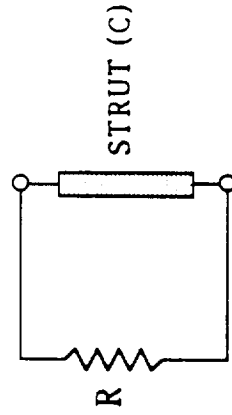
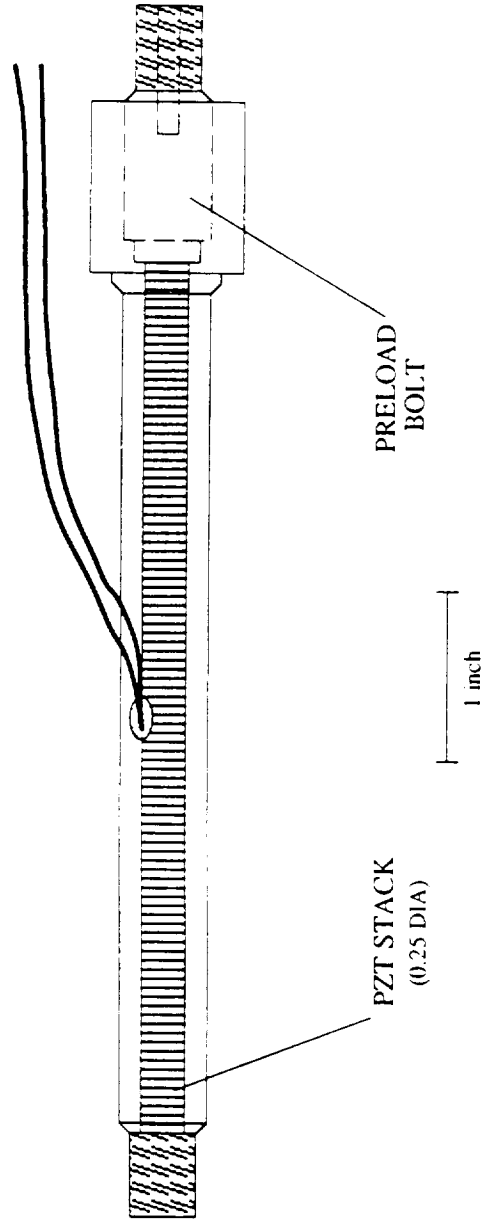
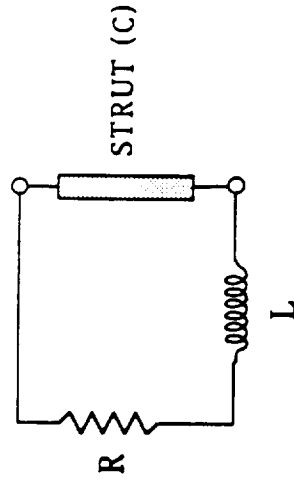


Figure 14: Locations of Struts with Highest Weighted Strain Energies

# Shunted Piezoelectric Damping



Resistive Shunting



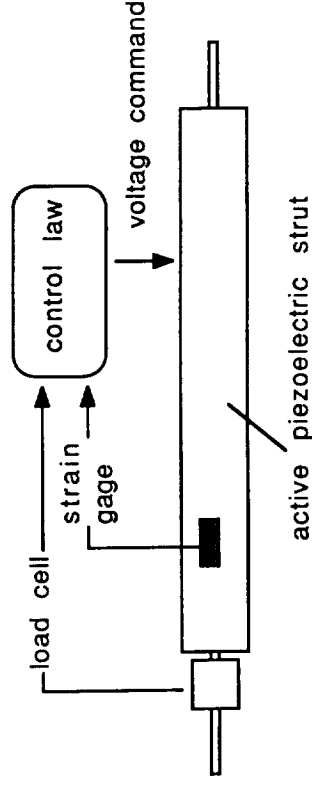
Resonant Shunting

# LOW AUTHORITY CONTROL

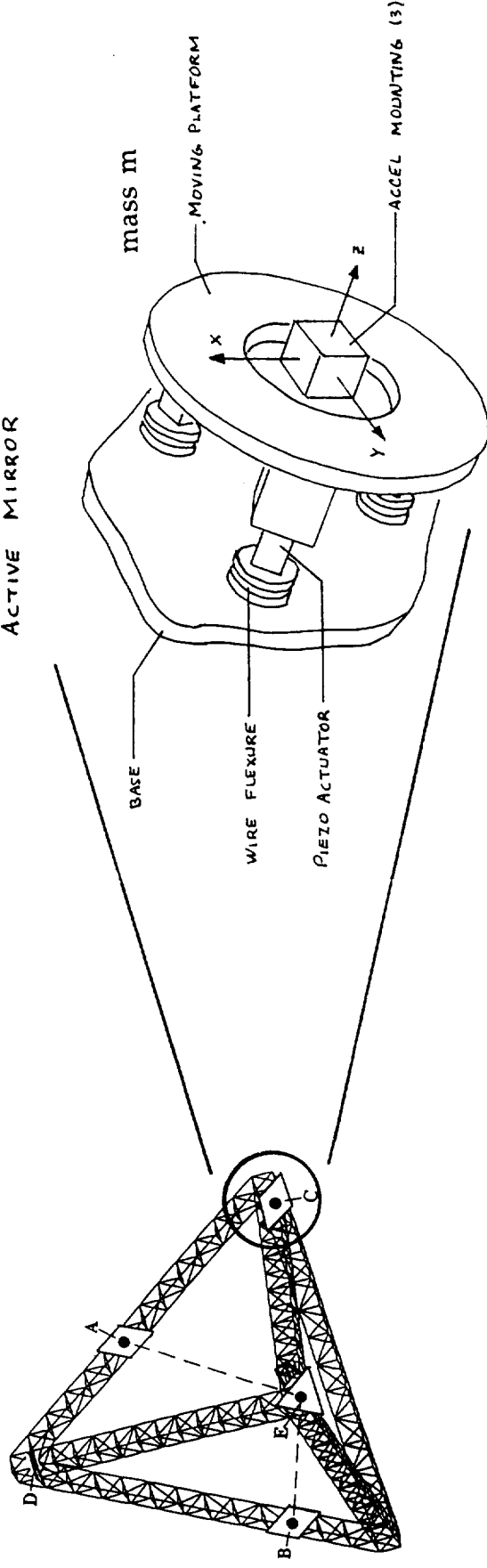
- adds some performance in control bandwidth
- adds robustness in rolloff region of high authority control
- similar benefits to passive damping

## Options:

- velocity feedback using active struts
- impedance matching/power flow approaches using external power source
- same formulation, but using passive elements only (shunted piezoelectrics)

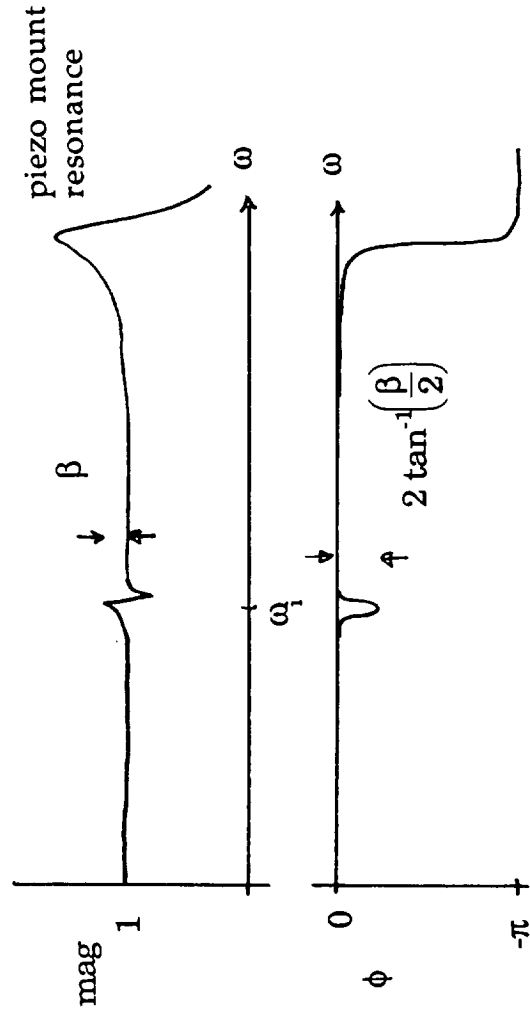


# Active Isolation of Lightweight Mirrors on Flexible Structures



- Plant transfer function is  $\frac{\text{mirror displacement}}{\text{piezo voltage}}$
- Active mirrors located at locations A, B, C
- Non-dimensional parameter for flex coupling of the  $i$ th mode:

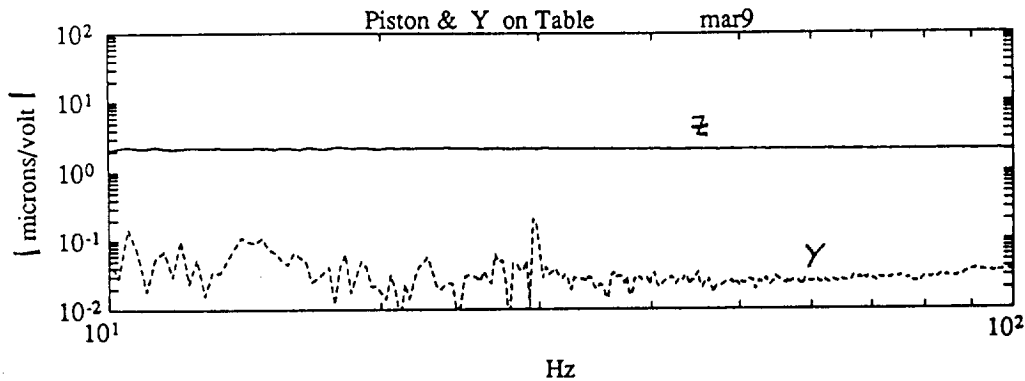
$$\beta = \left( \frac{1}{\zeta_i} \right) \left( \frac{m \phi_i^2}{2} \right)$$



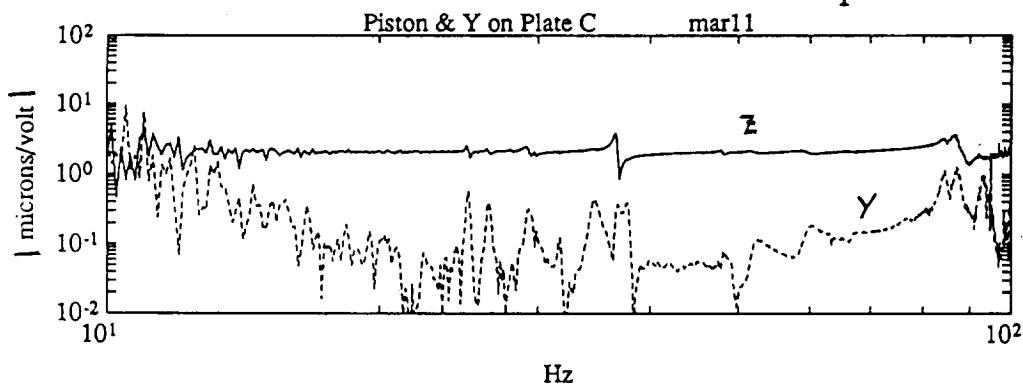
# Open Loop Transfer Function of Mirror

- mirror actuated in piston (z) direction only

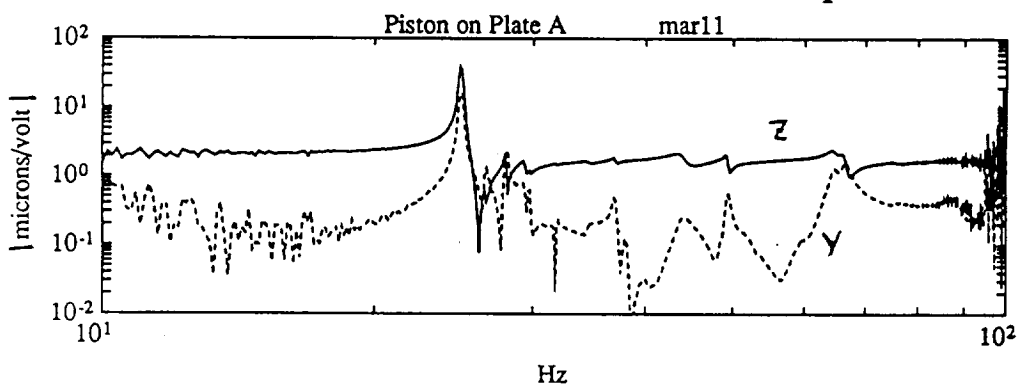
mirror mounted on rigid base



mirror mounted at truss vertex  
(plate C)



mirror mounted on truss beam  
(plate A)



# ***GLOBAL/HIGH AUTHORITY CONTROL***

Current areas of research:

Active strut placement

Sensor placement for control

Static shape control problem

Heirarchic control architectures that combine two or more levels of control design

Probabilistic formulation of control design

# ***SUMMARY***

Optical Interferometer testbed captures essential configuration, physics, and performance metric of a class of spacecraft

Student theses directed at different aspects of controlled structures design

Near-term plans are demonstration of local and global control approaches on testbed and evaluation with full optical performance metric